FEATURES

Capacitive vs. Inductive Sensing

Touch Trade-Offs

By
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Touch sensing has become an indispensable technology across a wide range of embedded systems. In this article, Nishant discusses capacitive sensing and inductive sensing, each in the context of their use in embedded applications. He then explores the trade-offs between the two technologies, and why inductive sensing is preferred over capacitive sensing in some use cases.

Touch sensing was first implemented using resistive sensing technology. But resistive sensing had a number of disadvantages, including low sensitivity, false triggering and shorter operating life. All of that discouraged its use and led to its eventual downfall in the market.

Today whenever people talk about touch sensing, they're usually referring to capacitive sensing. Capacitive sensing has proven to be robust not only in a normal environmental use cases but also underwater, thanks to its water-resistant capabilities. As with any technology, capacitive sensing comes with a new set of disadvantages. These disadvantages tend to more application-specific. That situation opened the door for the advent of inductive sensing technology.

In this article, we'll discuss capacitive sensing for embedded applications and how it can be used in various applications. We will then explore the use of inductive sensing in embedded products and why inductive sensing is preferred over capacitive sensing in some use cases. Finally, we'll compare the advantages of inductive sensing over capacitive sensing in these applications.

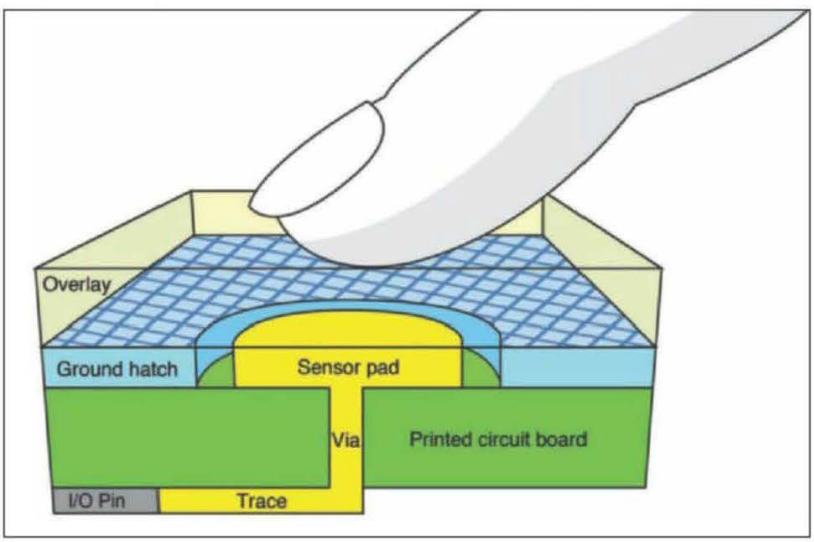

FIGURE 1
Capacitive sensing technique

CAPACITIVE SENSING FOR EMBEDDED

Capacitive sensing operates on the principle of monitoring the change in parasitic capacitance due to a finger touch (**Figure 1**). Capacitive sensing has been used primarily in two different forms: self-capacitance and mutual-capacitance. In self-capacitance mode, the net capacitance due to a finger touch and board capacitance is additive. This capacitance includes PCB traces and PCB materials like FR4, which has more capacitance compared to Flex materials and many similar dielectrics. Self-capacitance mode is useful in general touch application like buttons for touch-and-respond applications. In contrast, mutual capacitance is well-suited for applications involving more complex sensing such as gestures, multi-touch and sliders.

Mutual capacitance sensing uses two different lines: TX(Transmitter) and RX(Receiver). The Transmitter sends a PWM signal with respect to the system V_{DD} and GND. The Receiver detects the amount of charge received on the RX electrode.

One of the difficult use cases of capacitive sensing is that it cannot operate perfectly

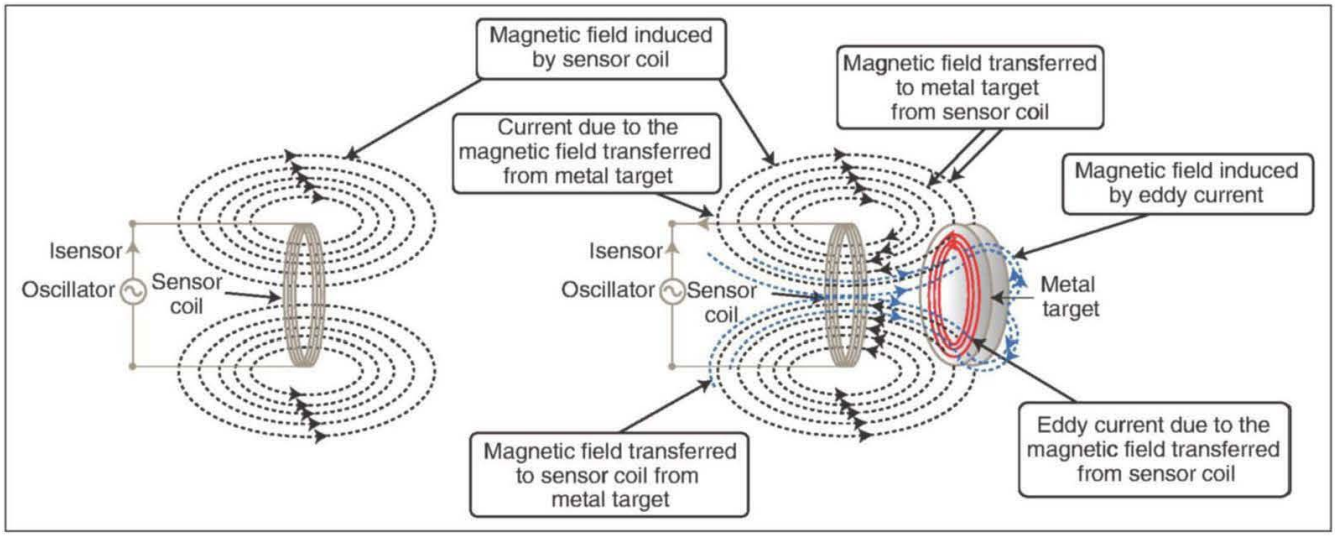
Magnetic field induced by sensor coil
Magnetic field transferred to metal target from sensor coil
Current due to the magnetic field transferred from metal target
Magnetic field induced by eddy current
Isensor
Oscillator
Sensor coil
Metal target
Magnetic field transferred to sensor coil from metal target
Eddy current due to the magnetic field transferred from sensor coil

FIGURE 2
Inductive sensing technique [1]

underwater. It also requires relatively strict design guidelines to be followed for error-free operation. Capacitive sensing performance is also impacted by nearby LEDs and power lines on PCBs. Implementing auto-tuning with variation in trace capacitance, variation in capacitive sensing buttons and different slider sizes and shapes all require different designs. Implementation challenges in industrial applications include using capacitive sensing with thicker glass material (display glass) and meeting capacitive sensor sensitivity requirements with those types of materials.

INDUCTIVE SENSING FOR EMBEDDED

Inductive sensing enables the next-generation of touch technology in applications involving metal-over-touch use cases such as in automotive, industrial and many embedded and IoT applications. Inductive sensing is based on the principle of electromagnetic coupling, between a coil and the target (**Figure 2**). When a metal target comes closer to the coil, its magnetic field is obstructed and it passes through the metal target before coupling to its origin. This phenomenon causes some energy to get transferred to the metal target—referred to as eddy current—that causes a circular magnetic field. Eddy current induces a reverse magnetic field, in turn leading to a reduction in inductance.

To cause the resonant frequency to occur, a capacitor is added in parallel to the coil to cause the LC tank circuit. As the inductance starts reducing, the frequency shifts upward changing the amplitude throughout. In contrast to a capacitive sensor, inductive sensing is able to operate reliably in the presence of water thanks to the removal of a dielectric from the sensor. This advantage brings inductive sensing touch sensing to a wide range of applications that involve liquids such as underwater equipment, flow meters, RPM detection, medical instruments and many others. Inductive sensing also supports biomedical applications. In general applications, inductive sensing enables replacement of mechanical switches and proximity sensing of metal objects. For example, in automotive applications, inductive sensing can be used to replace mechanical handles as well as detect car proximity. Some of these examples will be discussed in detail later.

Currently, the primary design challenge for implementing inductive sensing is designing coils with 100% production yield where inductive trace spacing is very narrow,

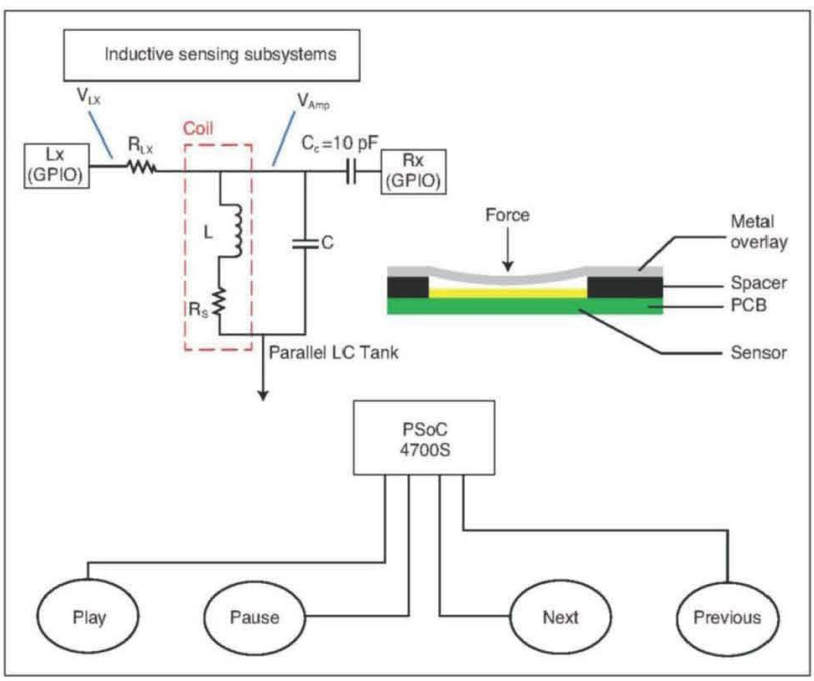

FIGURE 3
Shown here is the architecture of a water-resistant Bluetooth speaker using inductive sensing.

such as using 4-mil spacing. There is also the consideration of meeting inductive values with variations in PCB laminate materials.

USE CASES FOR EACH METHOD

Capacitive sensing is undeniably useful in a great many applications. However, for certain use cases inductive sensing offers greater reliability, ruggedness and usability.

Consider the use case of a Bluetooth speaker that needs to be water resistant and is intended for use in up to 2′ underwater for half an hour. This use case requires more than just that the product is functional underwater. It also requires that the user can adjust the speaker in these circumstances. Such operation needs to be simple, consistent and reliable—even in the presence of water.

With capacitive sensing, such operation is partially possible using mutual capacitive sensing employing complex shielding techniques. However, the device would offer a less than ideal user experience. For example, there would be inconsistent responsiveness from the touch interface. Due to changes in the dielectric introduced by the presence of water, its responsiveness would not be consistent with how the device operates when it is used out of water

For this application, metal-over-touch using inductive sensing would provide a consistent and reliable user performance (**Figure 3**). Alternatively, a mechanical button and/or dial could be used. However, a mechanical interface is costly compared to a coil printed on a PCB and connected to a few passive components. Additionally, a mechanical button can break or fail, providing a much shorter useable lifespan than an inductive button would.

Consider another use case employing proximity sensing: A vehicle detection system needs to monitor when another vehicle approaches within two meters and signal the driver on the dashboard or navigation panel. This functionality can be implement using inductive sensing. A hardware board containing multiple coils at different locations using a flex cable—all around the dashboard—can be designed around the four corners and center of the headlight areas (**Figure 4**). Data from the inductive coils is collected by an inductive sensing controller such as the PSoC 4700S from Cypress Semiconductor. The controller would then analyze the data to determine the presence or absence of other cars in a 4 m vicinity around the vehicle.

Capacitive sensing could also be used for vehicle proximity sensing. Inductive sensing is rugged, environment-independent, and easy to design and develop from an engineering point of view. In addition, little tuning is required to achieve the desired closed loop for a particular application.

Note: The controller need not be placed far away from the coils to improve signal-to-noise ration (SNR). Individual controllers can be used to optimize the design. The block diagram mentioned in Figure 4 is a principle representation.

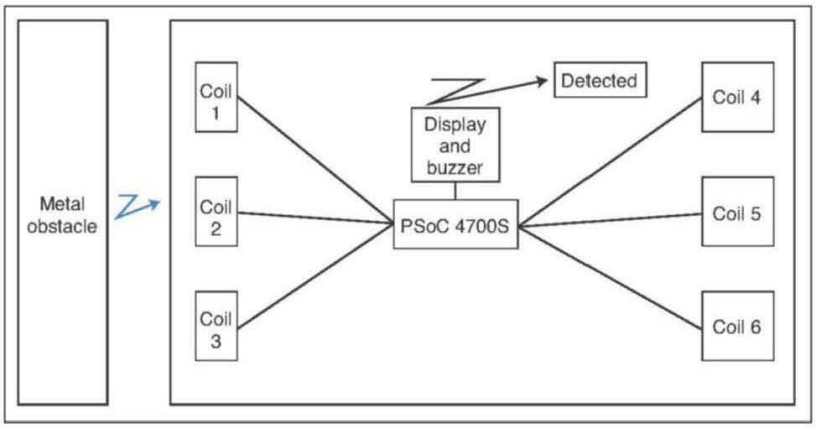

FIGURE 4
Using inductive sensing to determine vehicle proximity in an automotive application.

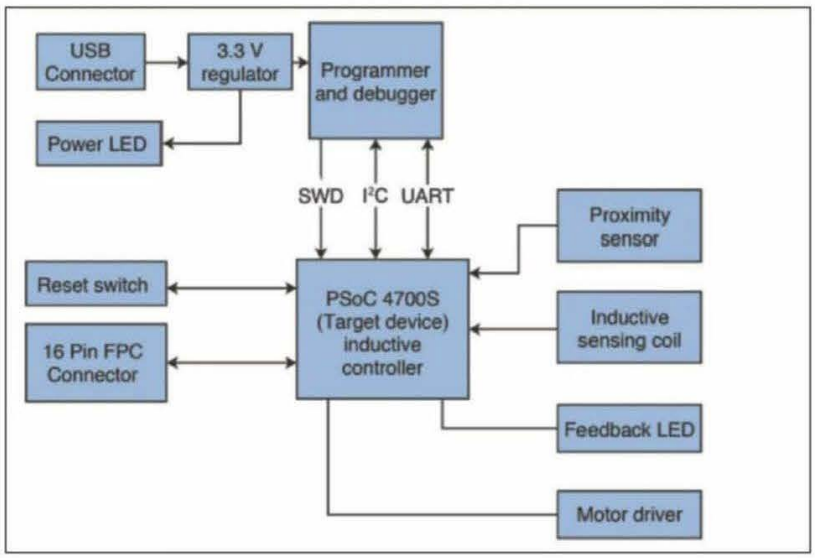

FIGURE 5
Inductive sensor block diagram

COMPARATIVE APPROACH

In general, designing an inductive sensor is fairly straightforward (Figure 3). A typical inductive sensor requires one or more inductive coils, as determined by the requirements of the

For detailed article references and additional resources go to:
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References [1] through [4] as marked in the article can be found there

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application. The sensor needs to be interfaced to the controller using suitable drivers or controllers to be understood by the microcontroller. This interface can be implemented using external components. However, to reduce system design and manufacturing complexity, some inductive controllers integrate driver and converter circuitry to convert inductive sensor data into raw counts which can then be processed using suitable algorithms. To learn more about the techniques involved in designing the circuitry around inductive sensing and controller check out Cypress' Inductive Sensing Evaluation Kit product page [2].

To program the inductive sensing controller, we need a suitable programmer—either on board or using external programmers. You need to decide the maximum power to be provided. Here we have shown the system at 3.3 V, however one can range from 1.8 V to 5 V. Next, all the interfaces in the design—like LEDs, motor drivers and so forth—need to be decided and placed accordingly. **Figure 5** shows the system level block diagram of an inductive sensing board.

Figure 6 shows the design flow involved in a typical inductive sensing application. First, assess how sensitive the system needs to be. Sensitivity determines the coil size and its number of turns. The application also impacts the shape of the coil. For example, a slider interface requires a series of squares or an elongated rectangle. The next step is to calculate the tank capacitor and the inductance based on the number of turns, spacing, width and diameter. To understand the detailed steps, refer to Cypress' Inductive Sensing Design guide [3].

Capacitive Sensing on the other hand requires measurement of theoretical capacitance with the required dielectric constant. During the layout, the designer is required to follow strict layout guidelines like ground shielding—CapSense traces have to have equal length for constant Cp and so forth. For more details on CapSense design, refer to Cypress' CapSense Design Guide [4].

Once these parameters are decided, the next step is to begin the mechanical design, specifically the overlay—also known as the metal target. An overlay comprises two materials whose specifications need to be decided: the metal target and the adhesive. The metal target material determines the amount of deflection and response. I recommend using an aluminum overlay for inductive sensing application because of its better deflection and response. For button applications, a higher Newton force on the overlay causes deflection throughout the overlay, leading to undesirable false triggering throughout the coils. For this use case, the user should only be able to press the buttons just enough to generate feedback. Pressing the overlay harder can even deform the overlay. Once all these things are intact, the board is designed and fabricated. The advantage of PSoC Creator IDE is it provides a user-friendly Inductive Sensing Tuner GUI which can be used by designers to serve their design needs.

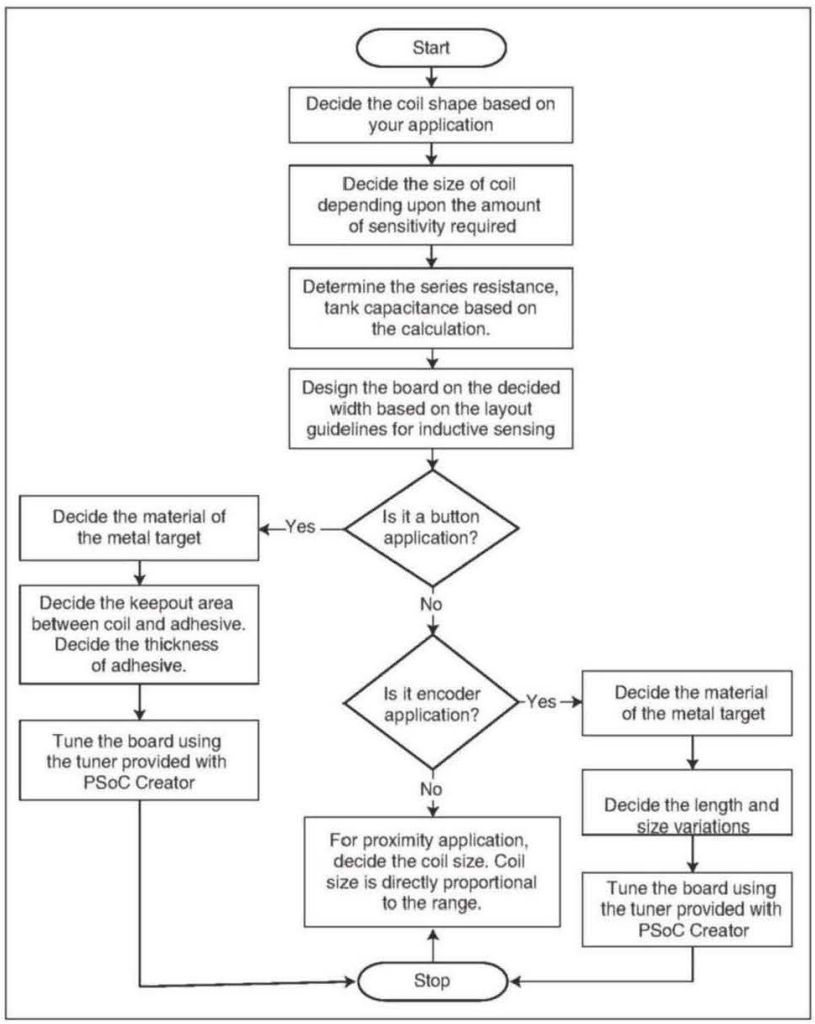
Start
Decide the coil shape based on your application
Decide the size of coil depending upon the amount of sensitivity required
Determine the series resistance, tank capacitance based on the calculation.
Design the board on the decided width based on the layout guidelines for inductive sensing
Is it a button application?
Yes
Decide the material of the metal target
Decide the keepout area between coil and adhesive. Decide the thickness of adhesive.
Tune the board using the tuner provided with PSoC Creator
No
Is it encoder application?
Yes
Decide the material of the metal target
Decide the length and size variations
Tune the board using the tuner provided with PSoC Creator
No
For proximity application, decide the coil size. Coil size is directly proportional to the range.
Stop

FIGURE 6
Design flow chart for a typical inductive sensing application

Both capacitive and inductive sensing enable OEMs to build intuitive, touch-based user interfaces to make their products more intuitive and easier to use. Because of its versatility, capacitive sensing has become the technology of choice in a great many applications. However, for applications where water tolerance is required, inductive sensing provides a robust and cost-effective alternative.

ABOUT THE AUTHOR

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